Electroformed Integral Shells for the Con-X HXT:Update

CfA

P. Gorenstein
S. Romaine
R. Bruni

OAB

G. Pareschi
O. Citterio
M. Ghigo
F. Mazzoleni
G. Parodi

MSFC

B. Ramsey
C. Speegle
J. Kolodziejczak
S. O'Dell

Outline of Electroformed Integral Shell Presentation

Introduction……………………………………...Paul Gorenstein

Multilayer deposition studies……………….Paul Gorenstein

Shell production and resolution…………….Giovanni Pareschi

Smaller diameter shells, MSFC activities…..Steve O'dell

Electroformed Integral Shells for the Con-X HXT

Integral Shells Team: SAO, OAB (Italy), MSFC

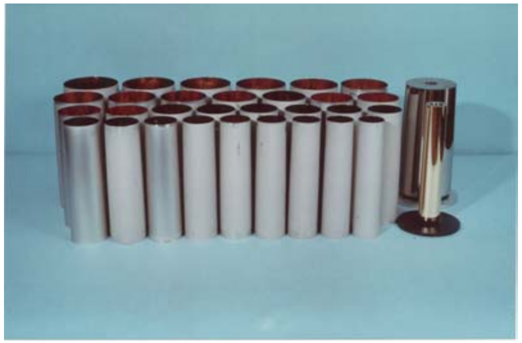
Advantages compared to segmented mirrors

- Expect better angular resolution from stiff closed shells as shown by experience: JET-X/SWIFT 17” HPD XMM-Newton 15” HPD
- Replication well adapted to making 12 or more identical copies
- Simpler integration of reflectors into a telescope, ~ 0.1 the number of parts

Challenges

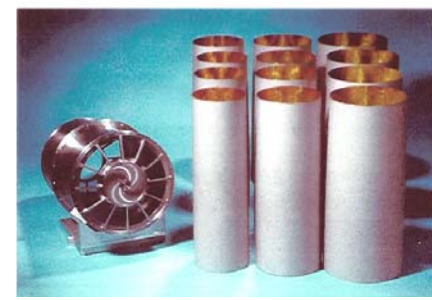
- Satisfying Con-X mass limit, < 160 kg for optics each S/C?
- Applying multilayer to the interior surface of a closed shell
- Obtaining low surface roughness
- Producing ~ 100 mandrels, 2x XMM-Newton

Heritage of Electroformed X-ray Telescopes

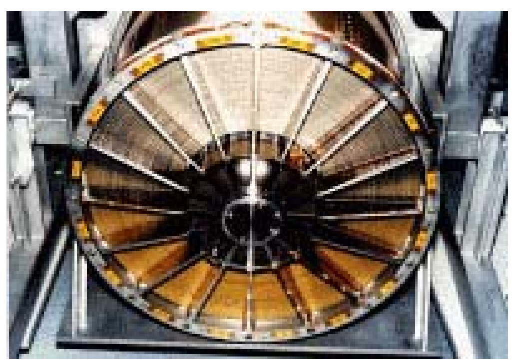


Beppo/SAX

JET-X/Swift



XMM-Newton



Requirements Beyond XMM-Newton

- Thinner shells: thickness/diameter < 0.3 XMM, (diam.> 23 cm)
- Longer shells: 70 to 80 cm compared to 60 cm
- Closer packing: especially important at small graze angles where aperture efficiency is small
- Larger number shells: about 2x XMM

Mass of Electroformed Shells for Con-X HXT Thickness/Diameter (T/D) Ratio

With a new, stronger Ni alloy the prescription for the shell thickness is:

T = 100 microns for D < 23 cm

$T/D = 4.33 \times 10^{-4}$ for D > 23 cm

for D > 23 cm this is 0.30 of the XMM T/D ratio and allows us to satisfy the limit upon the mass of the optics

Responsibilities

SAO: Depositing multilayer coatings and overall management of integral shell schedule

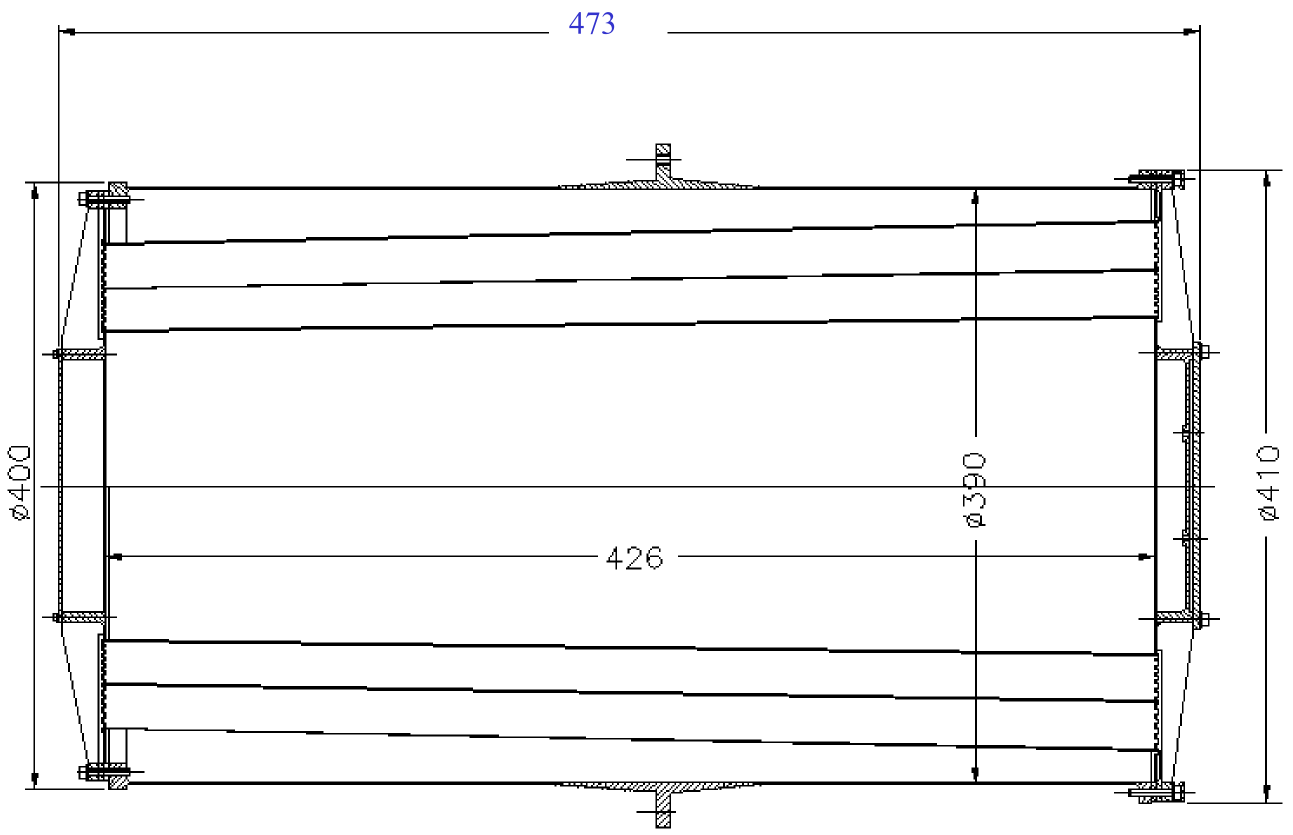
OAB: Producing larger diameter shells and assembly of prototype

MSFC: Producing smaller diameter shells and research into faster and cheaper mandrel production

Several Studies Proceeding in Parallel

- Producing thinner shells from existing JET-X/SWIFT mandrels (rougher surfaces) and testing resolution in soft X-rays
- Depositing multilayer coatings on the interior surfaces of shells produced from small mandrels with smooth surfaces and measuring performance
- Producing mandrels less expensively and more expeditiously
- Preparations for tests of pre-prototype in summer 2003

Pre-Prototype Mirror



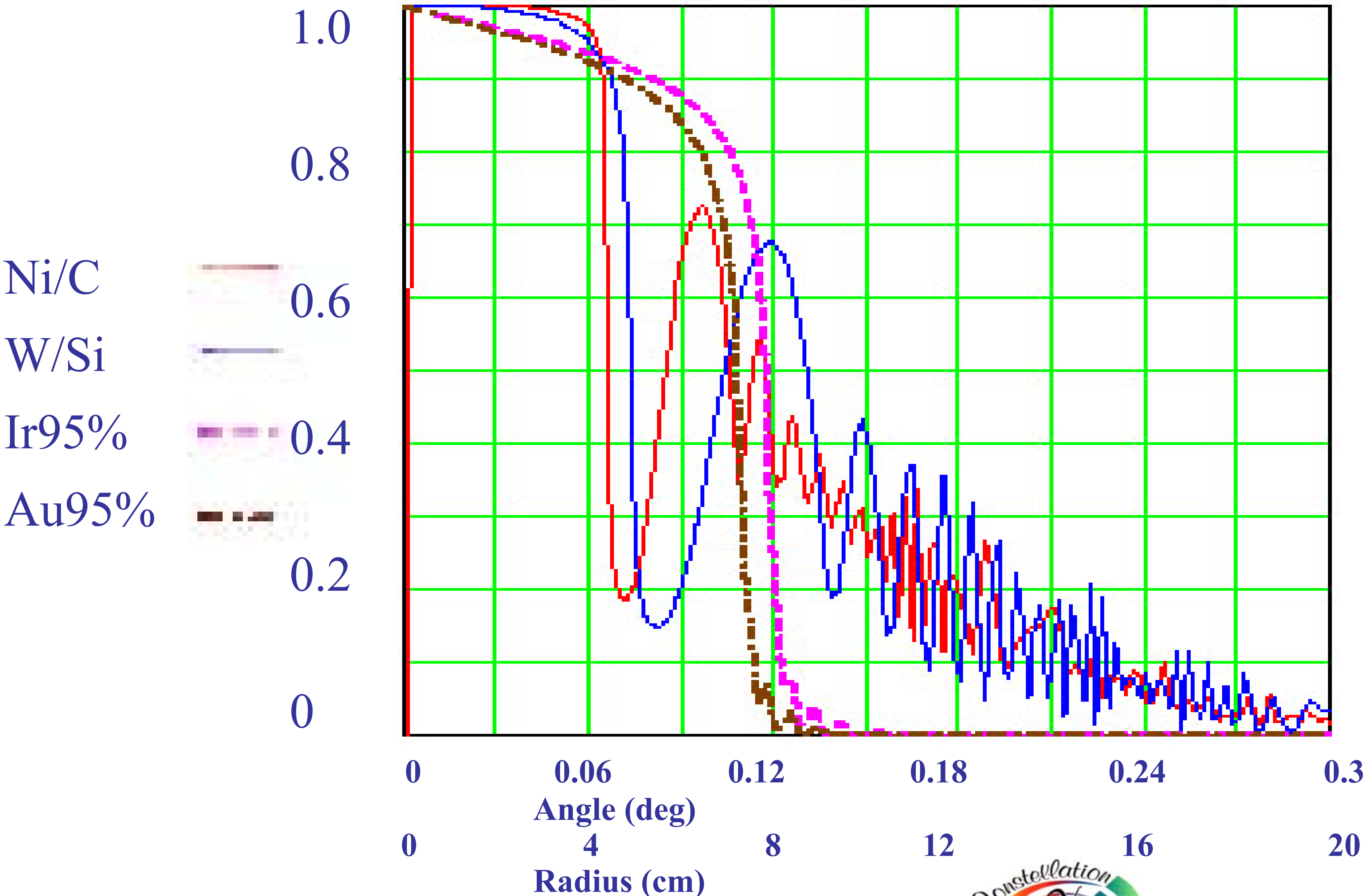
Pre-Prototype Mirror, Coatings

Plan for 5 shells, 4 with W/Si multilayer,

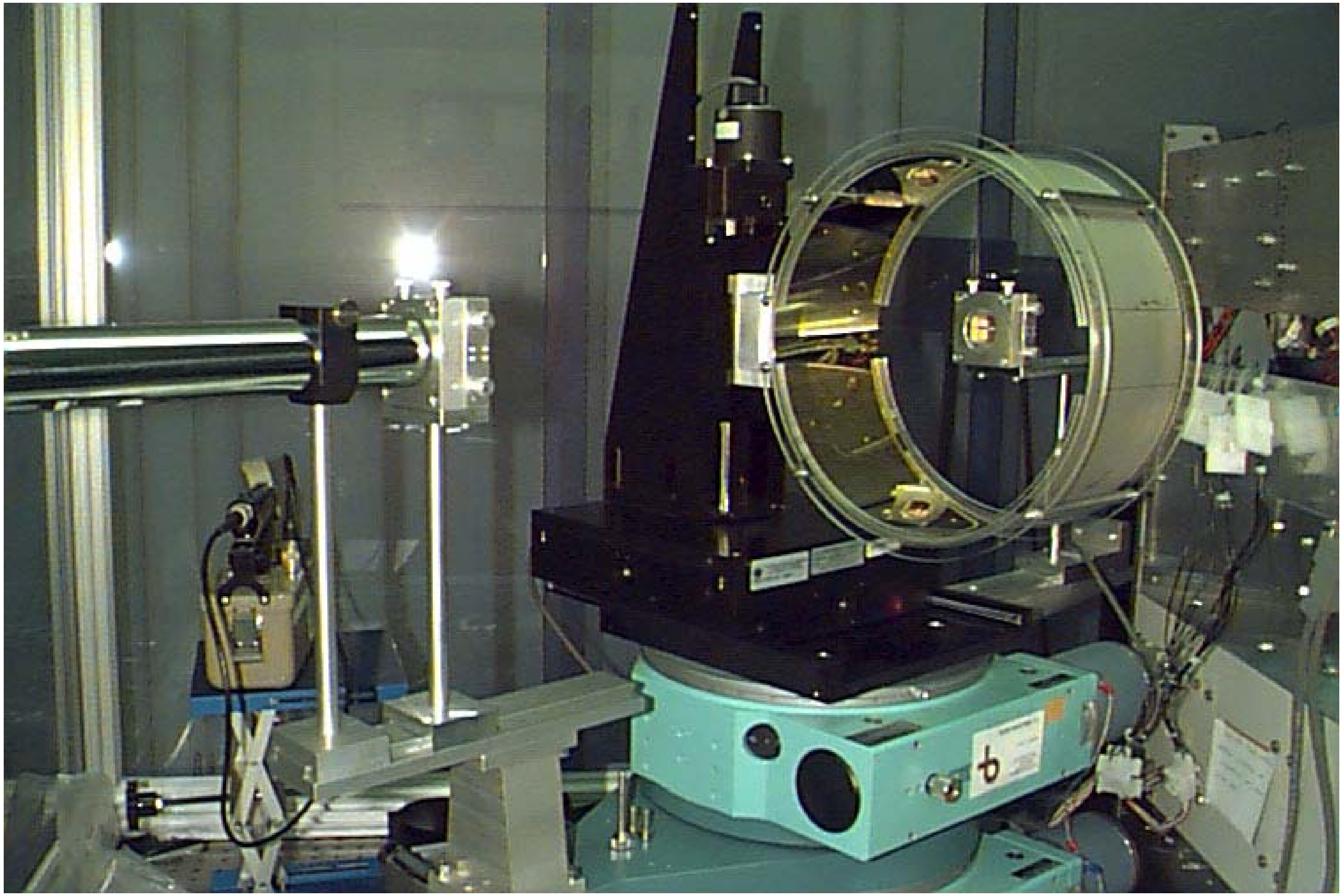
1 (innermost) with Iridium (MSFC)

For the pre-prototype, coatings will be deposited on all the shells
There is no need to deposit coatings on the mandrel and transfer them to the shell.

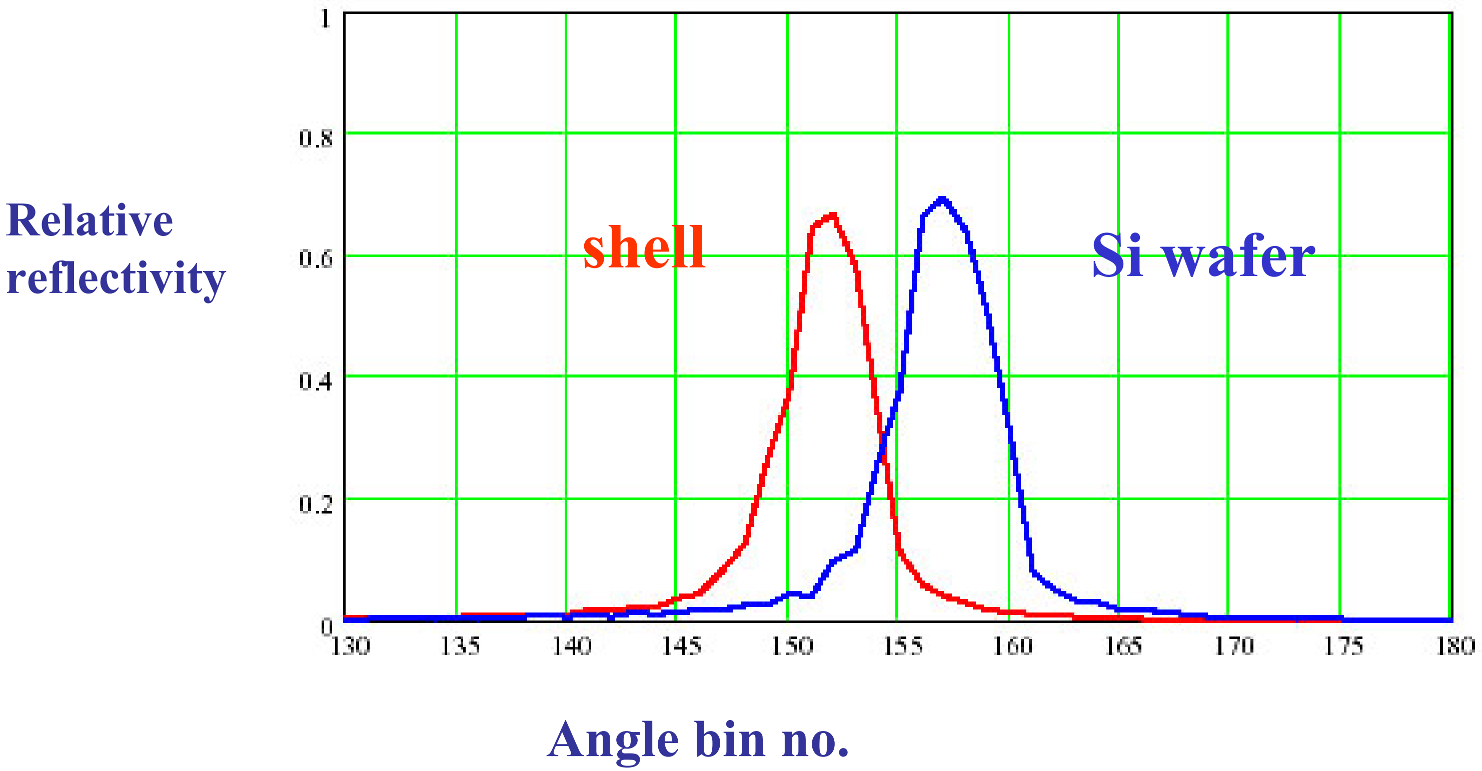
40 keV Reflectivity Vs. Angle for Several Coatings



Small length shell with multilayer, 8 keV testing



8 keV reflectivity of multilayer (uniform period) deposited on 30 deg. azimuthal section of interior surface of shell



Coating Mandrels

SAO is able to apply coatings to the mandrel for transfer to the shell following separation.

This process is logistically more complex than coating the shell, at least during this phase when shell production and coatings are occurring at different locales.

There is no need to coat mandrels for the prototype but we have not yet shown that coating shells results in superior performance

SAO Multilayer Deposition Chamber Configured to Coat Mandrel

Outline of activities at OAB:

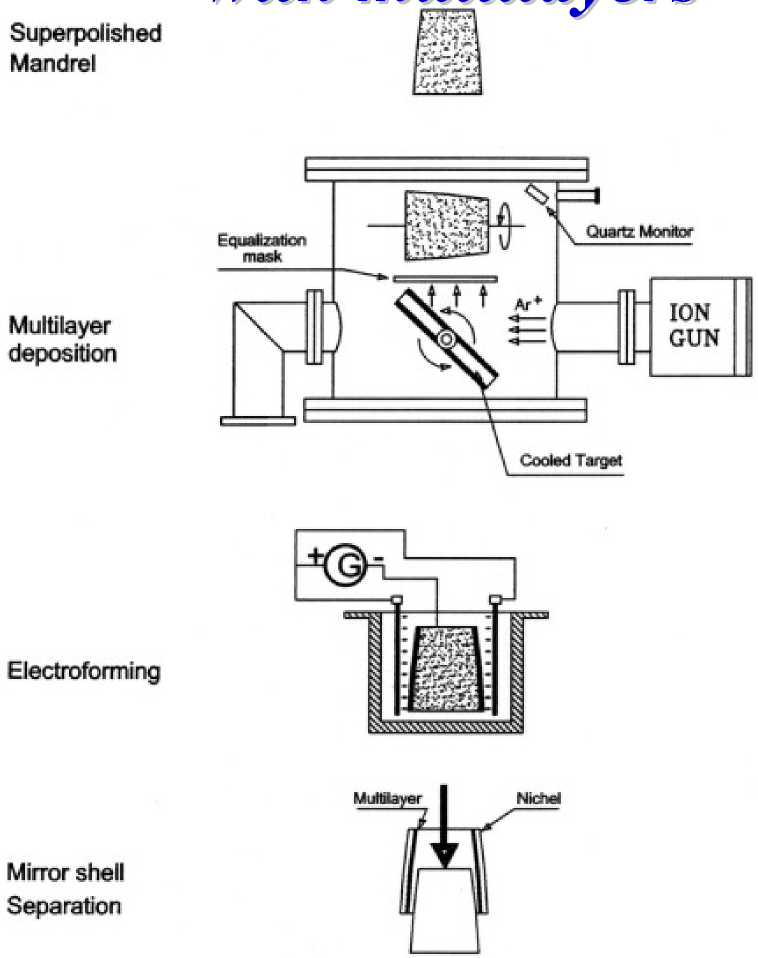
- short review of the development work carried out until now;

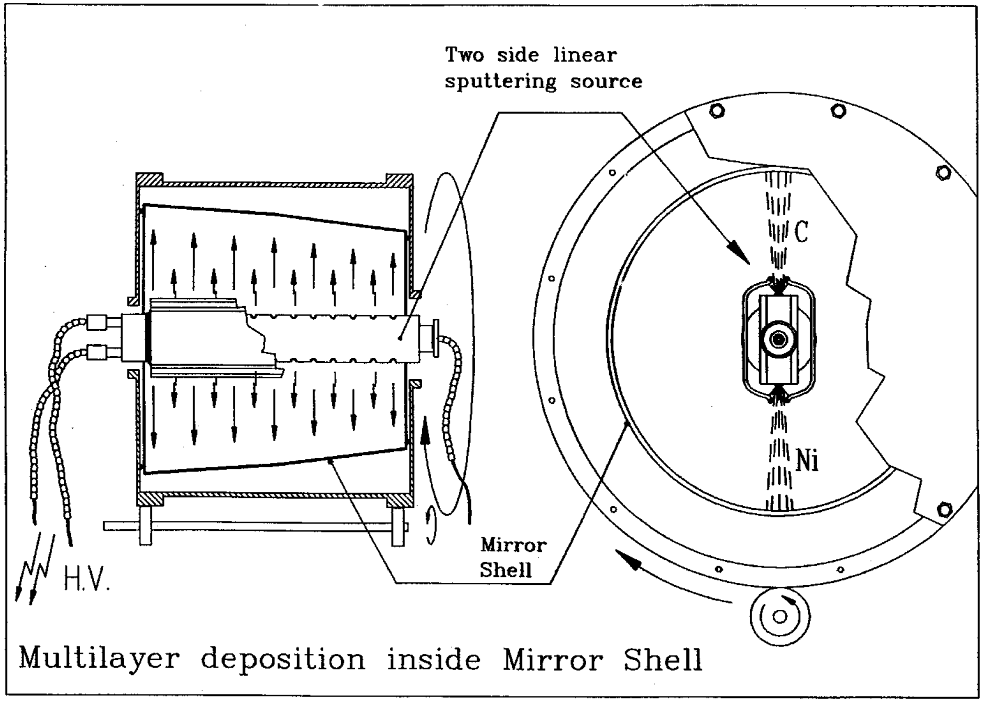
- the problem of the ***Con-X/HXT*** mass budget ➔ how to meet it assuming the replication by Ni electroforming approach;

- recent X-ray imaging tests (July ’02) on an Au coated thin **(130 μm)** JET-X/Swift mirror shell;

- design of a proto-prototype technology demonstrator for ***Con-X/HXT***

Two methods of coating electroformed shells with multilayers





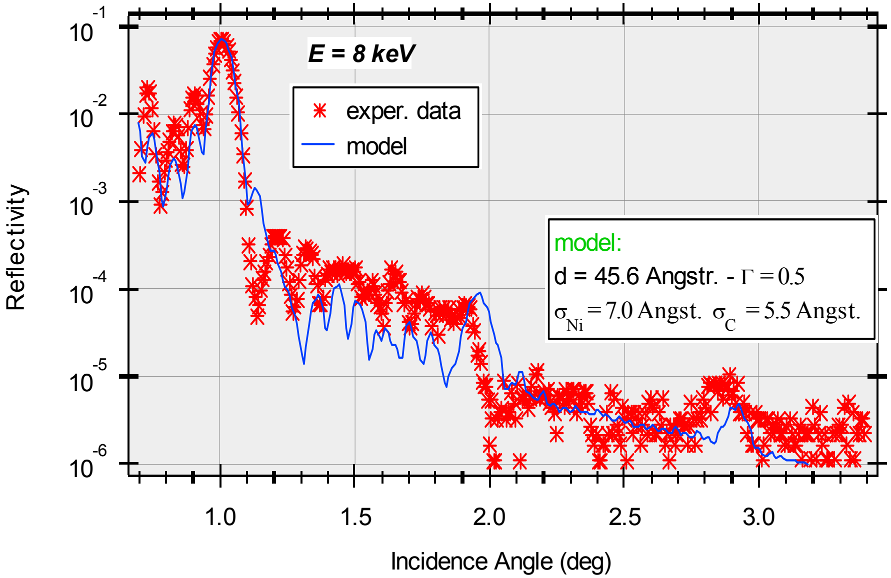
A) "direct" replication of the multilayer film

B) deposition of the multilayer film onto the internal Au surface of a replicated mirror shell

Direct replication of a ML mirror prototype from a SAX mandrel

- *the double-cone mandrel (#12) roughness level was 7 Å rms (vs. the goal of 2 Å rms)*

- *a Ni/C ML (11 bi-layers) has been successfully deposited and replicated by Ni electroforming;*



- *the D-W roughness measured by X-ray reflectivity tests @ 8 keV was 7 Å, i.e. in agreement with the initial quality level of the mandrel surface.*

Superpolishing

- a crucial point is given by the surface quality of the mandrel (it has to be much better than for Au-coated soft X-ray mirrors!);

- a superpolishing prototype machine has been developed at OAB for this specific task;

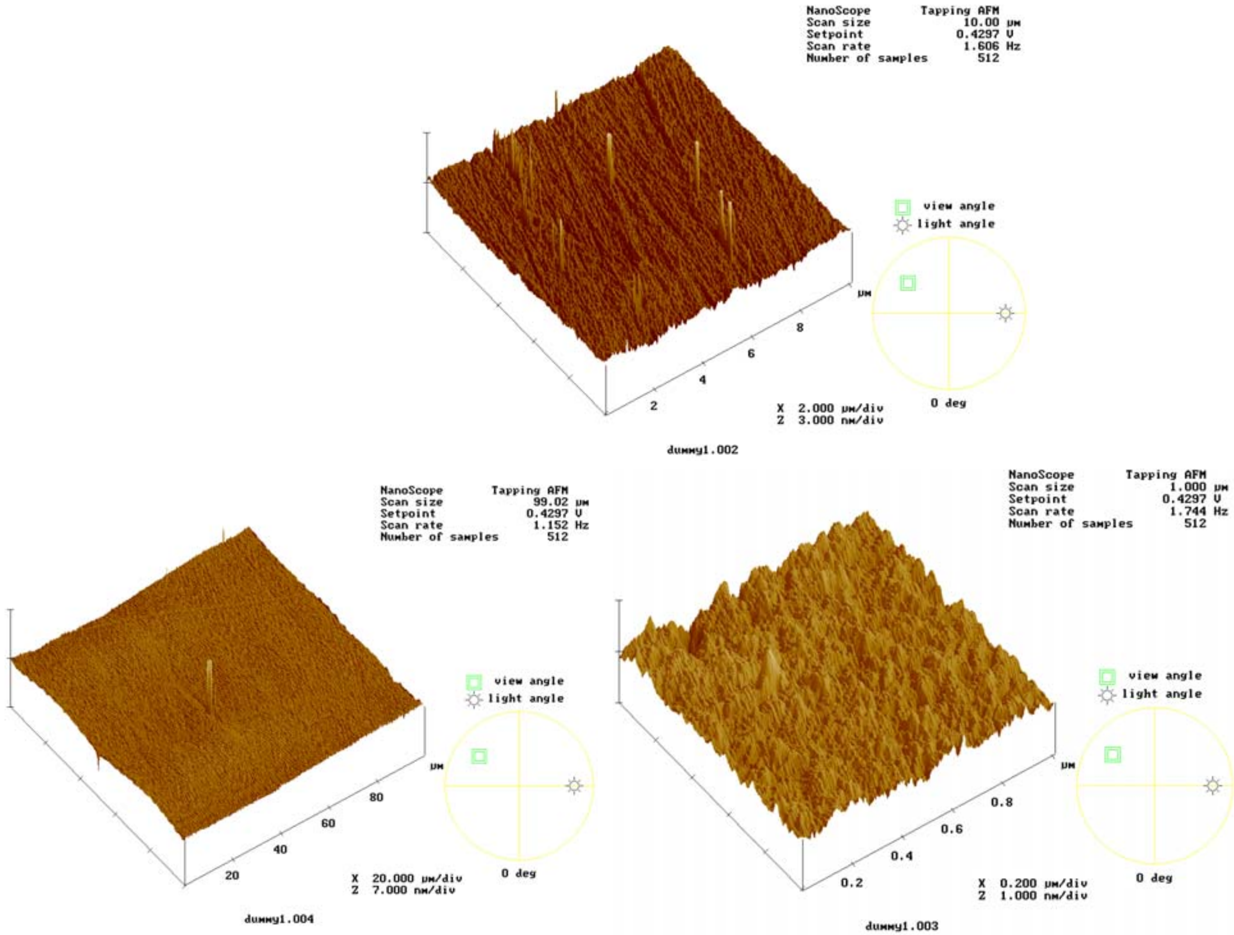
- representative single-cone mandrels (height = 15 cm, Ø = 28 cm, a = 0.2°) have been successfully superpolished.

In the table the roughn. values achieved by the new lapping method on a prototype mandrel surface are compared to those of the SAX mandrel #12

Instrument	**Scan Length *(µm)***	**Roughness rms (Å) SAX #12 mandr.**	**Roughness rms (Å) Superpolish. mandr.**
WYKO -2.5 X	***6000.0***	***N. A.***	***10.1***
WYKO -20 X	***660.0***	***7.6***	***3.0***
AFM	***10.0***	***6.2***	***2.4***
AFM	***1.0***	***3.4***	***1.8***

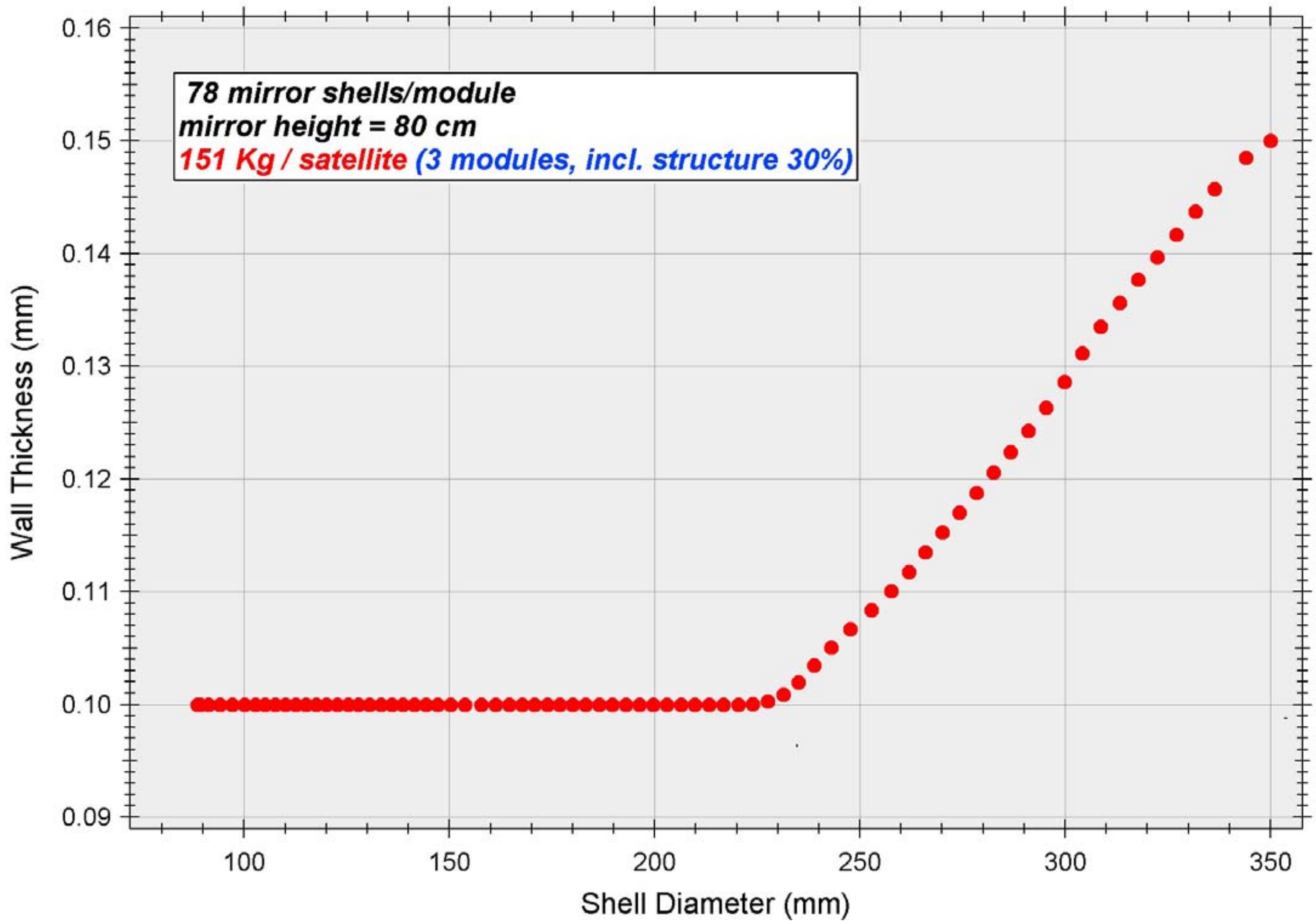
Low roughness level maintained also for the replicated surface

Au coated MS produced by Ni electroforming replication
Height = 150 mm – Ø = 280 mm



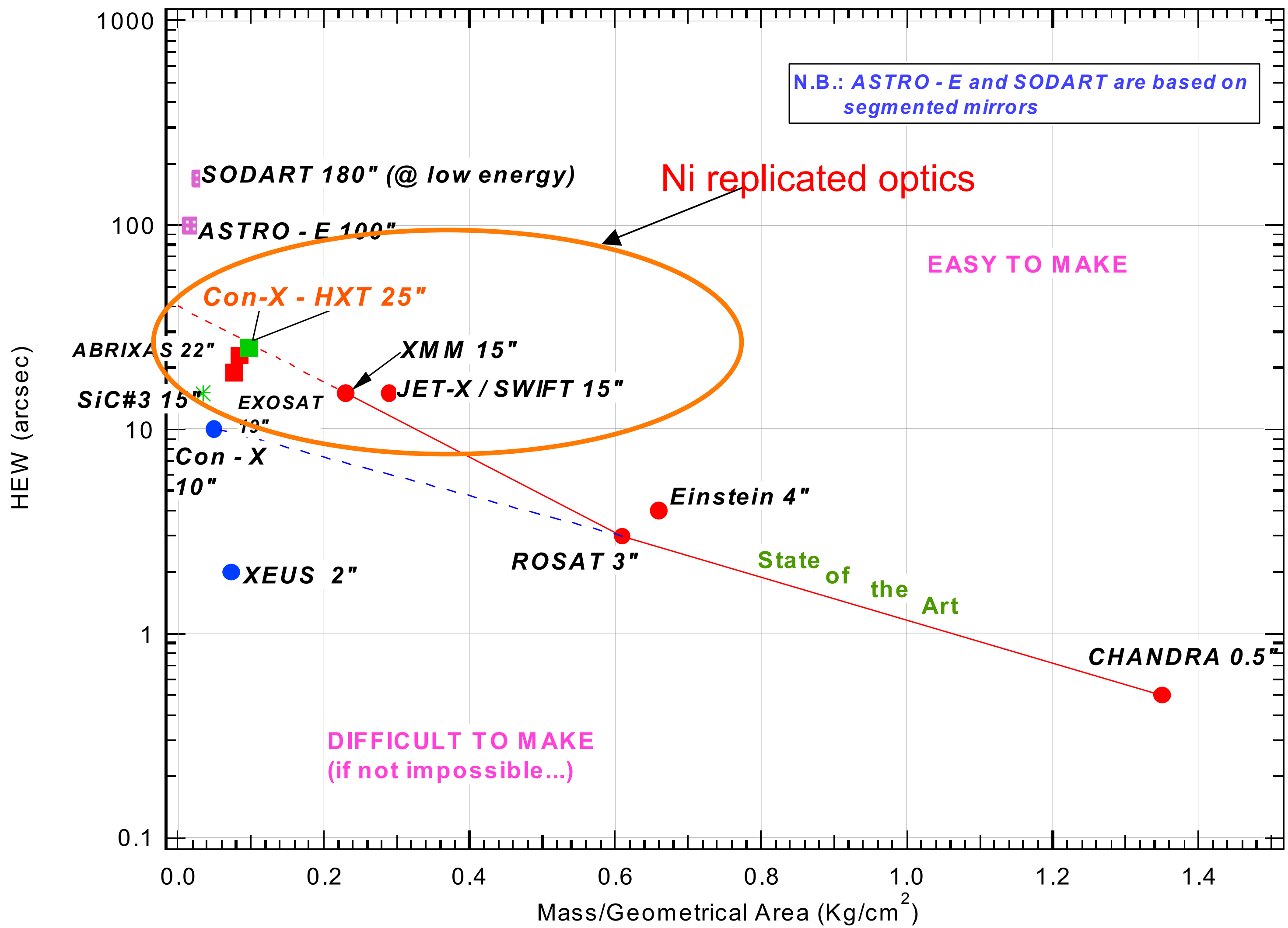
	Scan Length *(µm)*	***Mandrel σ rms (Å)***	***Au σ rms (Å)***
AFM	***100.0***	***3.0***	***5.1***
AFM	***10.0***	***2.4***	***2.6***
AFM	***1.0***	***1.8***	***1.9***

Thickness vs. diameter (possible) sequence to meet the mass budget (195 Kg/satellite including the detector units)



Note I: the mass of the optics case + spiders has also been included
Note II: to meet the mass limit the mass-to-diameter ratio has to be diminished *of a about factor 8 compared to JET-X/Swift*

Expected HEW for the assumed Mass/Geometrical-Area ratio

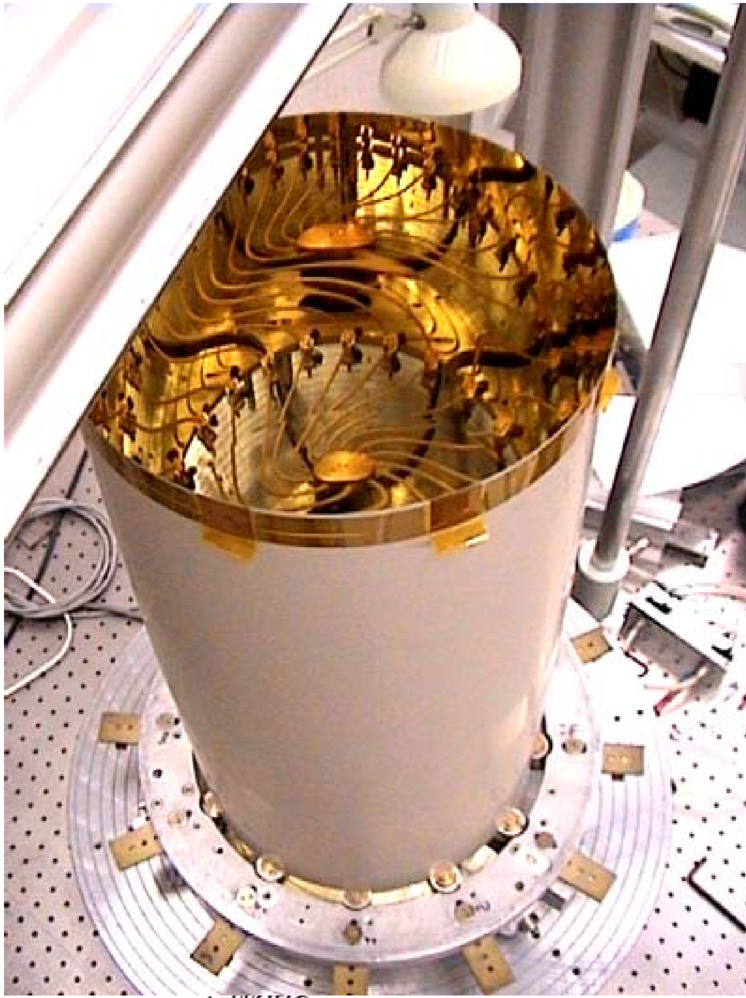


Fabrication of a thin (130 μm) Au coated MS from the largest JET-X mandrel

To verify the imaging capabilities of thin Ni electroformed mirrors, we produced a 13 μm Au coated shell exploiting the largest JET-X mandrel

➔ *the thickness has been diminished of a factor* **8.5** *with respect* JET-X/SWIFT

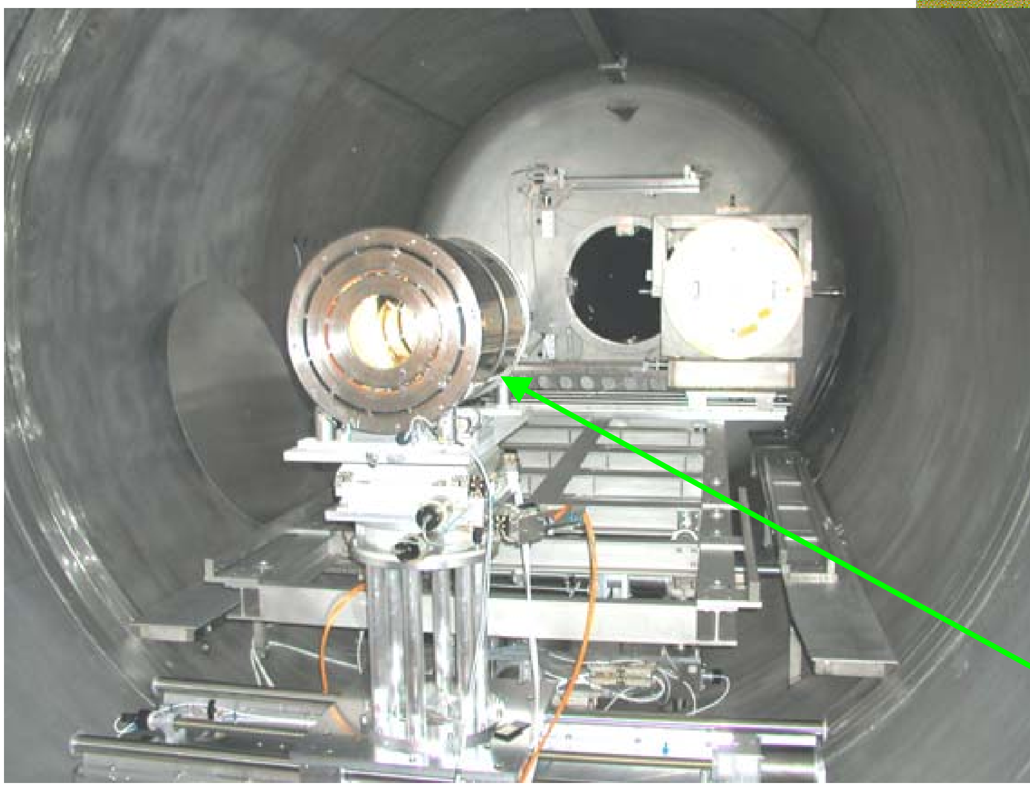
∅ = 30 cm	Height = 60 cm
Focal Length = 3.5 m	
Thickness = **130 μm**	Mirror mass = **660 g**



The Au coated thin m.s. with stiffening rings before integration

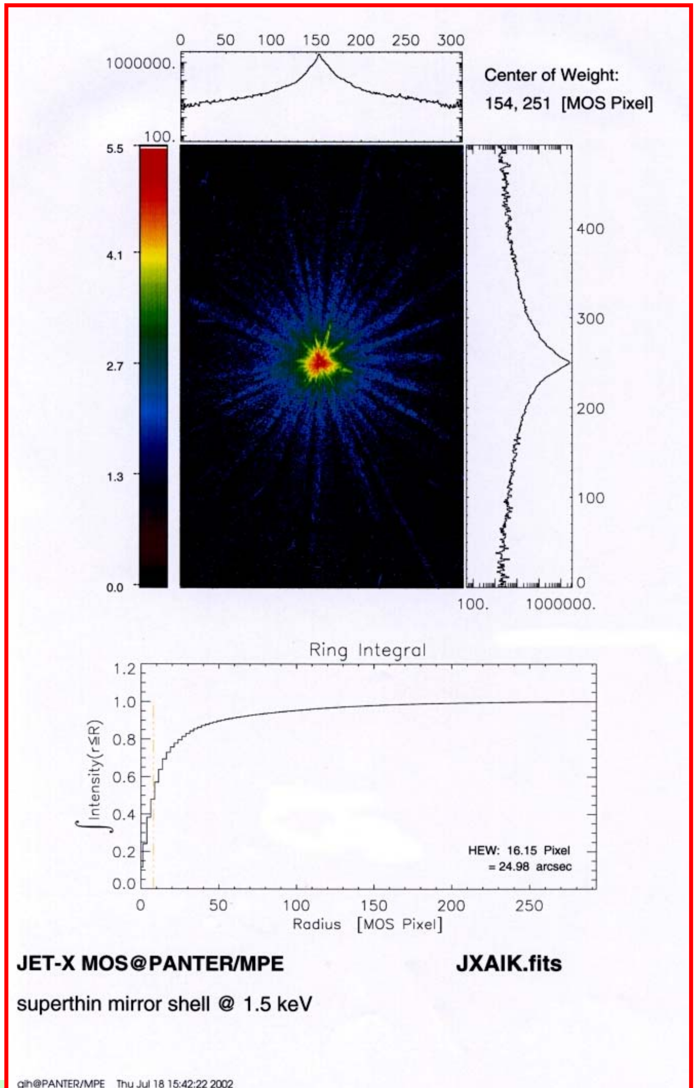
- Two stiffenning rings are inserted to restore and to maintain the MS roundness;
- The rings are removed after integration.

Full-illumination X-ray tests at the Panter-MPE facility (July '02)



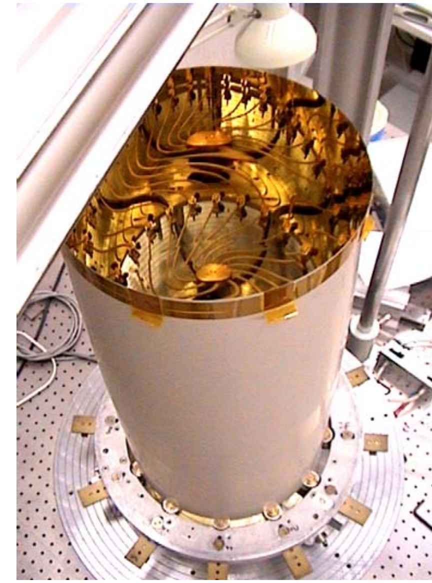
The m.s. integrated in the optics case inside the test chamber at Panter-MPE

X-ray imaging test of a thin JET-X mirror shell (July '02)



X-Ray test @ Panter-MPE (July '02) - **E = 1.5 keV**

- diam. = 30 cm
- thickness = 130 μm
- wall thickness ***8.5 times*** less than JET-X



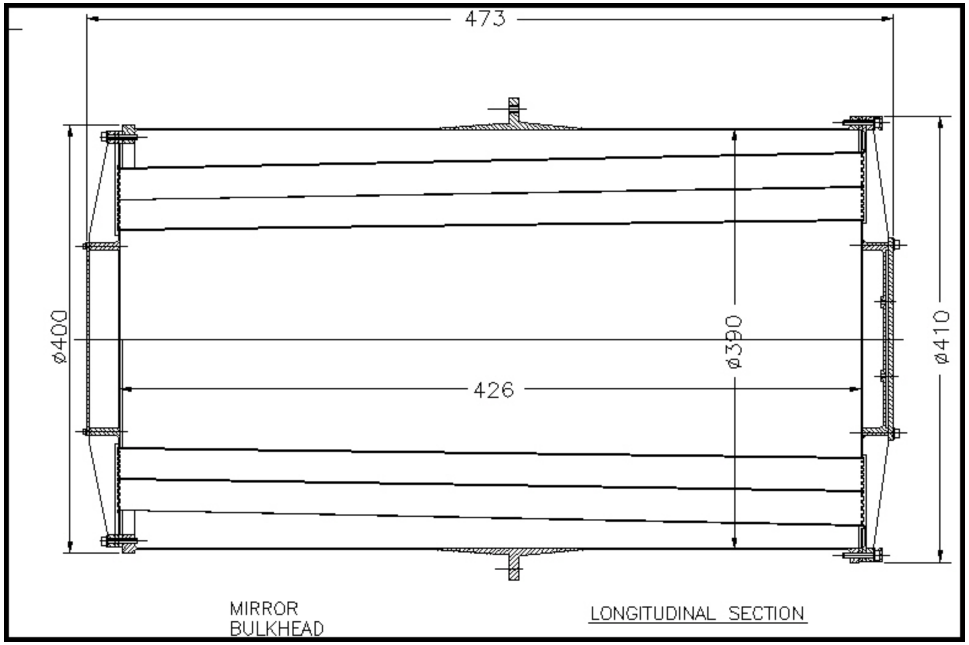
HEW$_{meas}$ = 25 arcsec

X-ray test - HEW : 25 arcsec

HXT imaging request: ≤ 60 arcsec

SAO/OAB/Marshall proto-prototype scheme to prove the technology

Focal Length = 10000 mm
Mirror length = 426 mm



- ✓ 3 MS (∅ = 250, 270, 280 mm) provided by OAB;
- ✓ deposition of the multilayer films at CfA;
- ✓ 2 additional MS (∅ = 240 and 150 mm) provided by NASA/Marshall (➔ B. Ramsey). The 150 mm shell will be coated with just an Ir single layer;
- ✓ integration at OAB;
- ✓ full-illumination tests with the 102 m Hard X-ray facility at NASA/Marshall.

X-ray tests schedulated for: July 2003

Hard-X-Ray Electroformed-Nickel Optics at MSFC

- *HERO Balloon Program*
- *Shells for Con-X HXT prototype*

HERO BalloonProgram

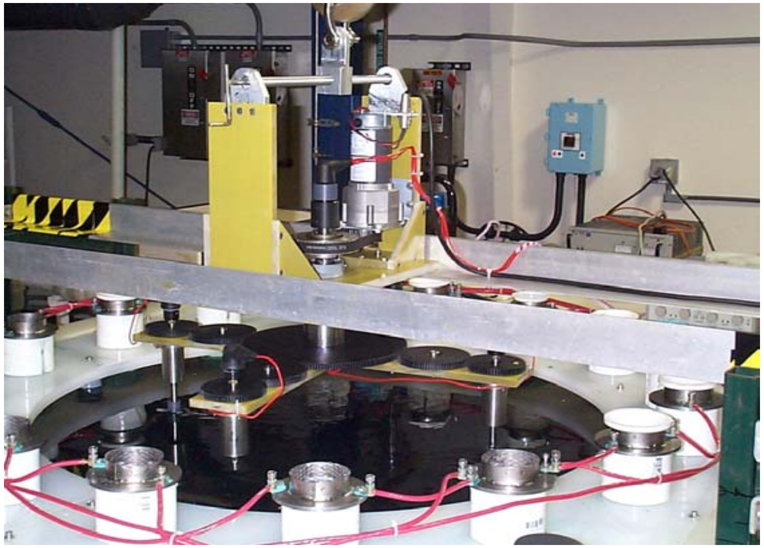
- HERO, for High Energy Replicated Optics is an evolutionary balloon program.
- Utilizes in-house-fabricated hard-x-ray mirrors *plus* supporting x-ray detectors, gondola and pointing system.
- Optic design philosophy :
  - Utilize a large number of shallow-graze-angle, iridium-coated full-shell mirrors
  - Obtain significant collecting area by using narrow-aspect ratio mirror shells (ie large length to diameter ratio), by nesting many thin shells and by using multiple mirror modules.
- Cost Factor :
  - Keep costs down by utilizing inexpensive grinding for mandrel figuring
  - Develop simple polishing machines
  - Electroform multiple shells simultaneously

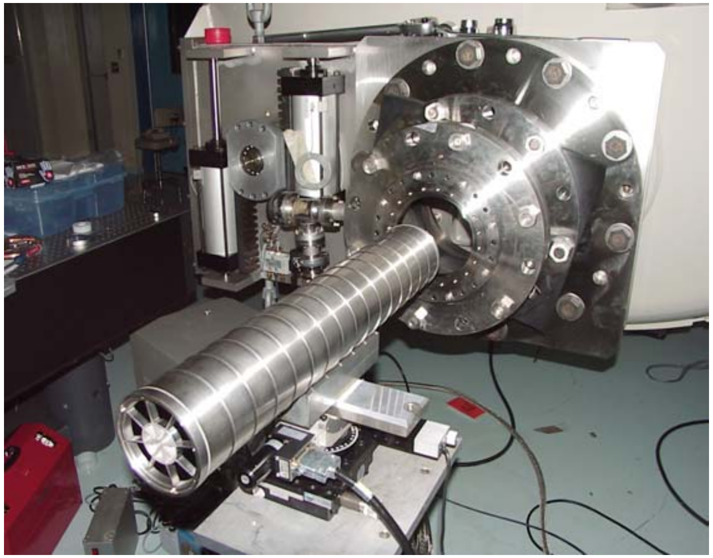
HERO: Current Activities

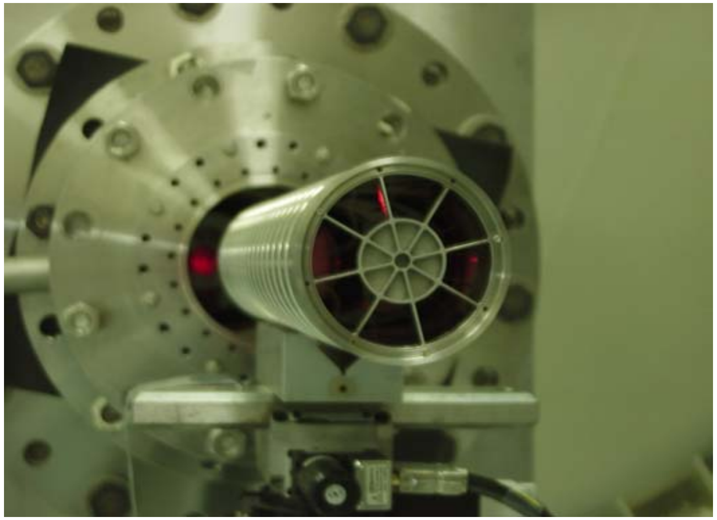
Successful proving flight in May 01

- New Gondola being fabricated
- Mirror modules
  - 15 shells per module ranging from 50 to 95 mm diam. d
  - Shell length = 60 cm
  - Shell thickness = 0.25 mm
- Angular resolution
  - 15 arcsec HPD goal
- Number of modules
  - 8 by 2003
  - 16 by 2004 – >200 cm^2 at 40 keV. …this will give a sensitivity 1000 times greater HEAO-3 survey

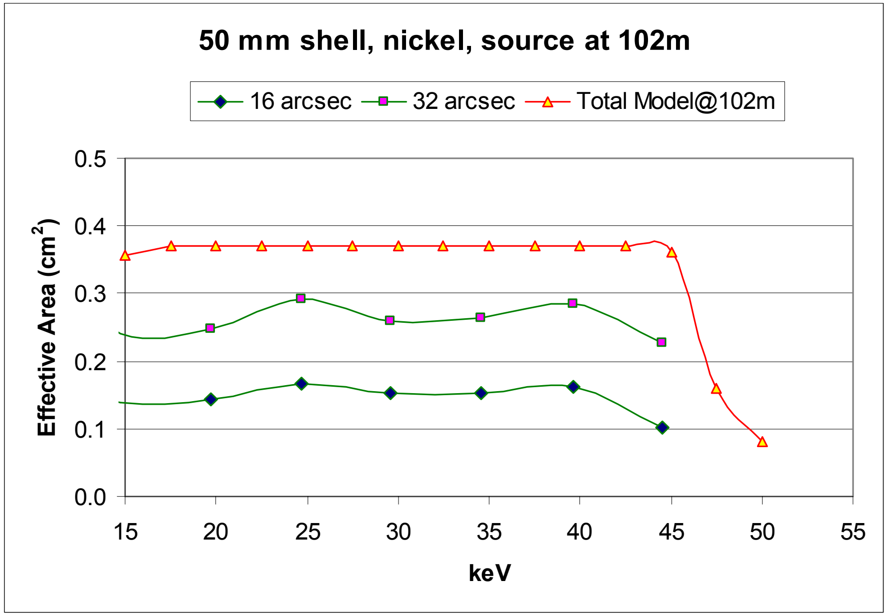
HERO: Recent Mirror Fabrication and Tests

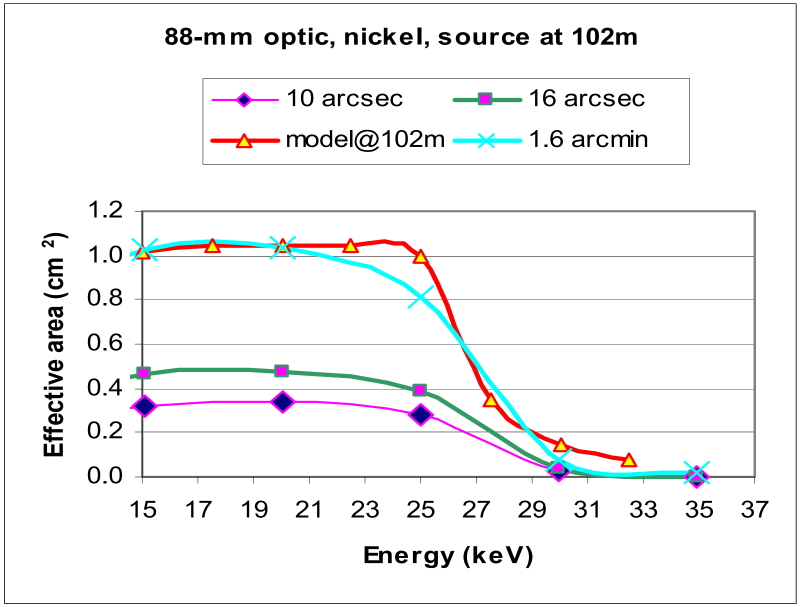


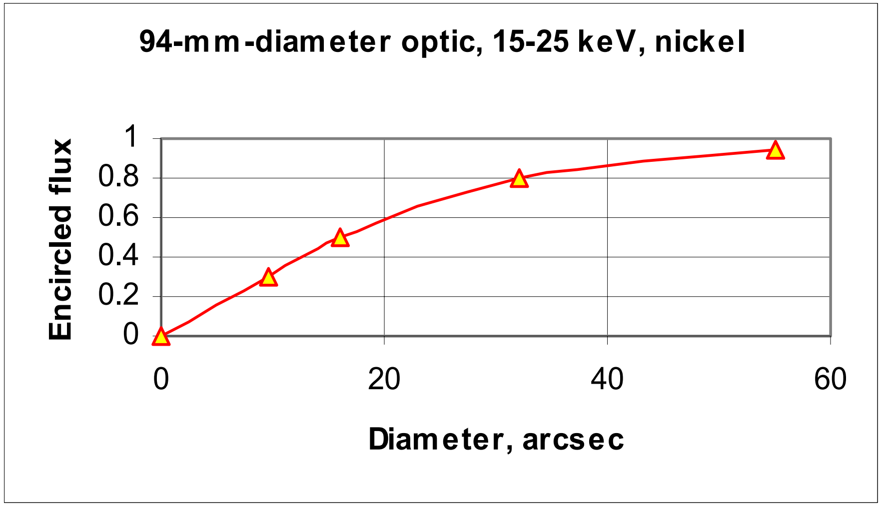


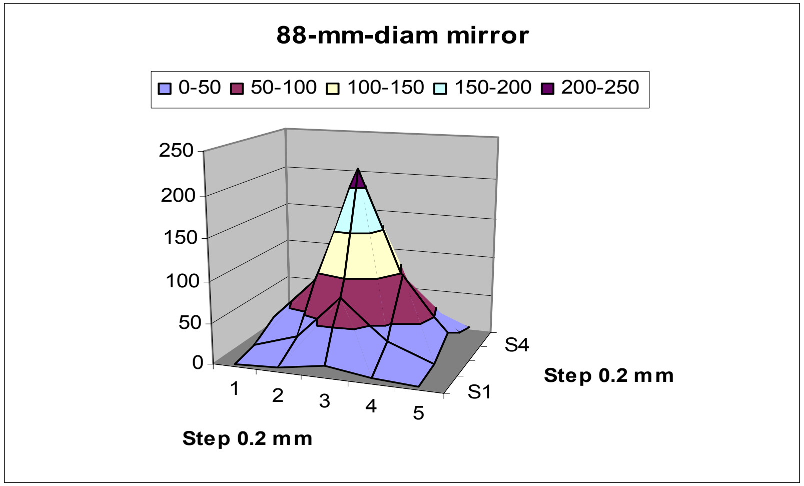


HERO: Recent (Aug-02) Mirror Tests Results









- **Some developments of relevance to Con-X HXT**
    - Low cost mandrel production (<30k / mandrel)
    - High strength alloys permit very thin shells
    - Release under water/alcohol provides low-stress separation of thin shells
        - *High angular resolution demonstrated*
- **To meet the (original) weight budget of HXT requires shells ranging from ~ 10 cm to ~ 35 cm diameter, and thickness from 0.1mm to 0.15 mm.**
    - HERO shells are 0.25 mm thick, 9.4 cm diameter (outer)
        - *But 50 cm diameter, 0.15-mm-thick shells have also been fabricated*

- MSFC plans to provide 2 shells for the nickel HXT prototype :
  - 23-cm diameter, 43-cm long, 0.1-mm thick, multilayer (SAO) coated
    - Delivery, Dec 02
  - 15-cm diameter, 43-cm long, 0.1-mm thick, Ir coated
    - Delivery, Mar 03
- Status
  - Both mandrels have been designed
  - Larger is in fabrication
    - Polishing tests in progress
      - For multilayers ideally need surface roughness lower than for Ir-coated optics
      - Coupon tests with sol-gel, 50 nm alumina, gives 2.7 Å rms on WYKO x 20, 3.3 Å RMS with AFM (5 μm x 5 μm)
        - » Do not anticipate problems achieving this on the mandrel.